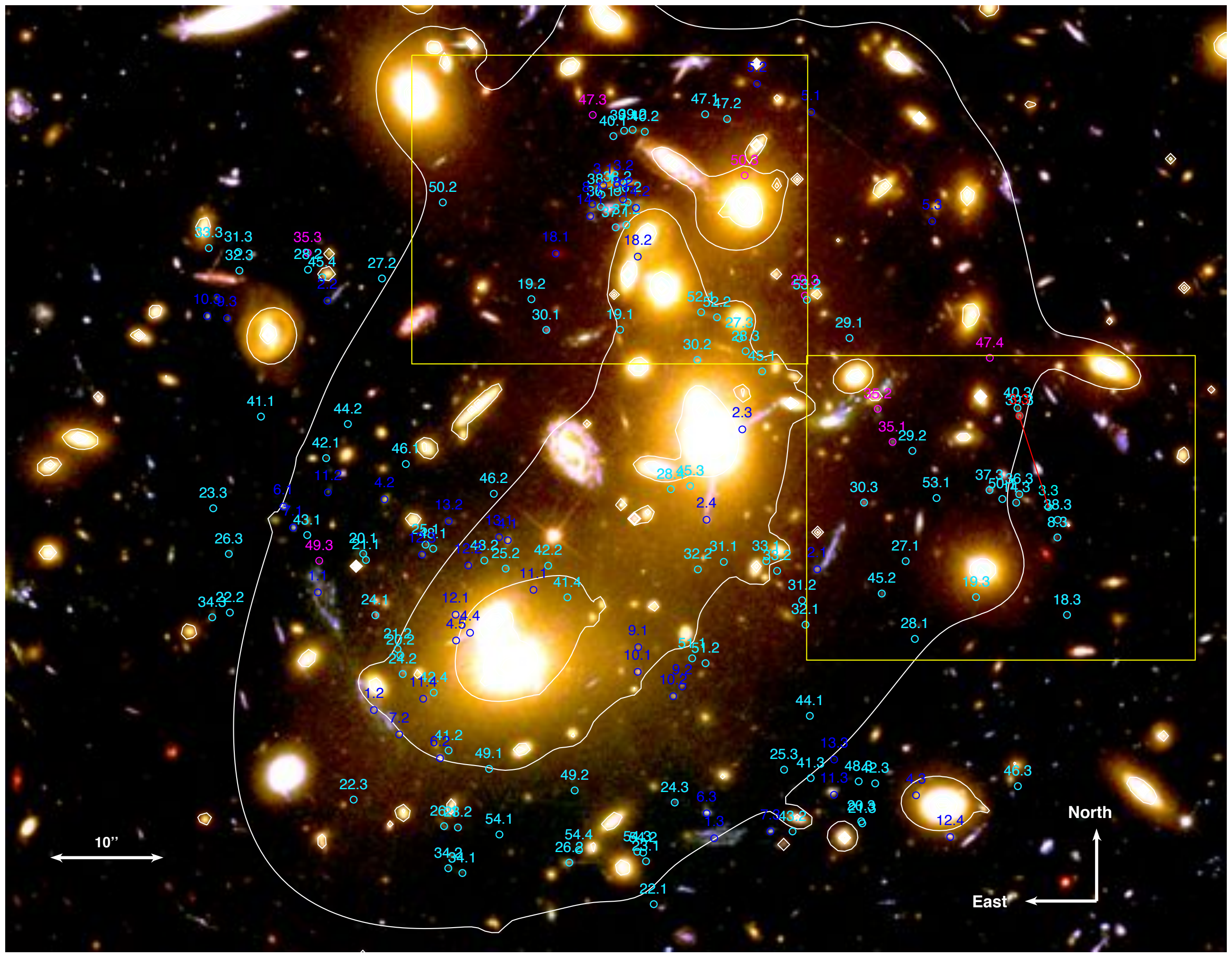
The Effect of Large-Scale Structure on the Magnification of High-z Sources by Cluster-Lenses*

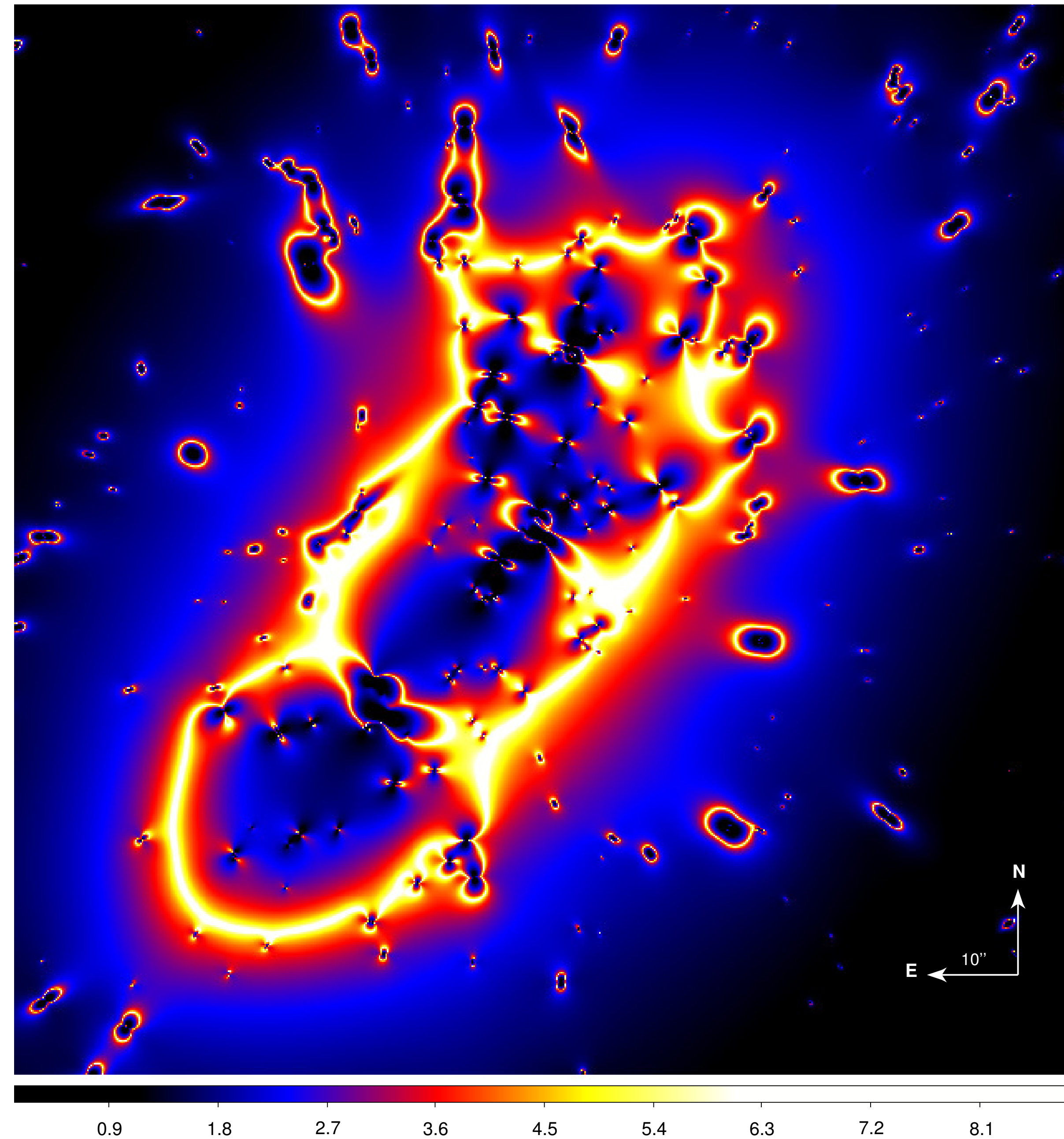
Anson D'Aloisio
University of Washington, Seattle
University of Texas at Austin

Collaborators: Priyamvada Natarajan & Paul R. Shapiro

*MNRAS, 445, 3581 (arXiv:1311.1614)

HFF Precision Magnification Maps





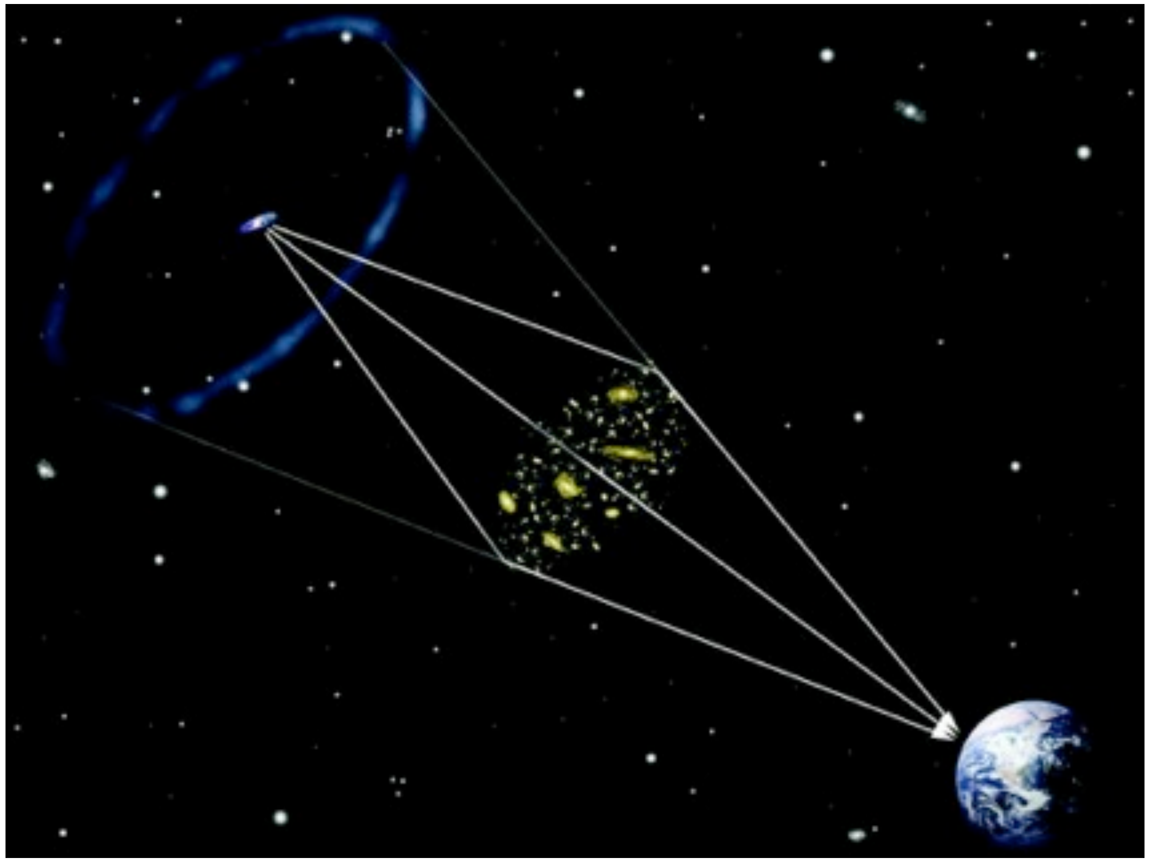
- Groups already reporting statistical uncertainties in μ as low as a few percent!

*Example from Jauzac et al. 2014

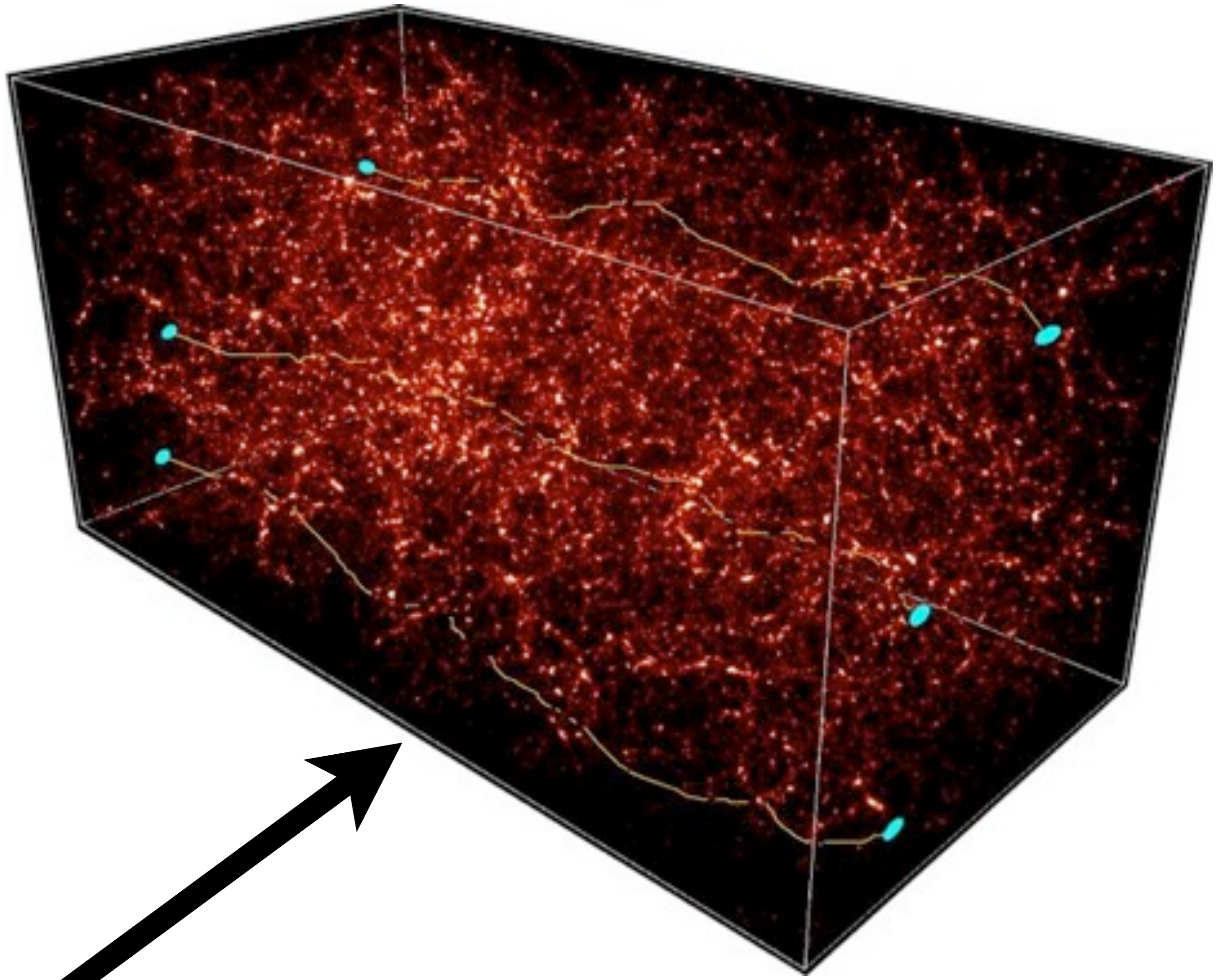
Intervening Large-Scale Structure

Strong-Lensing by Cluster

Weak Lensing by LSS



http://www.lsst.org



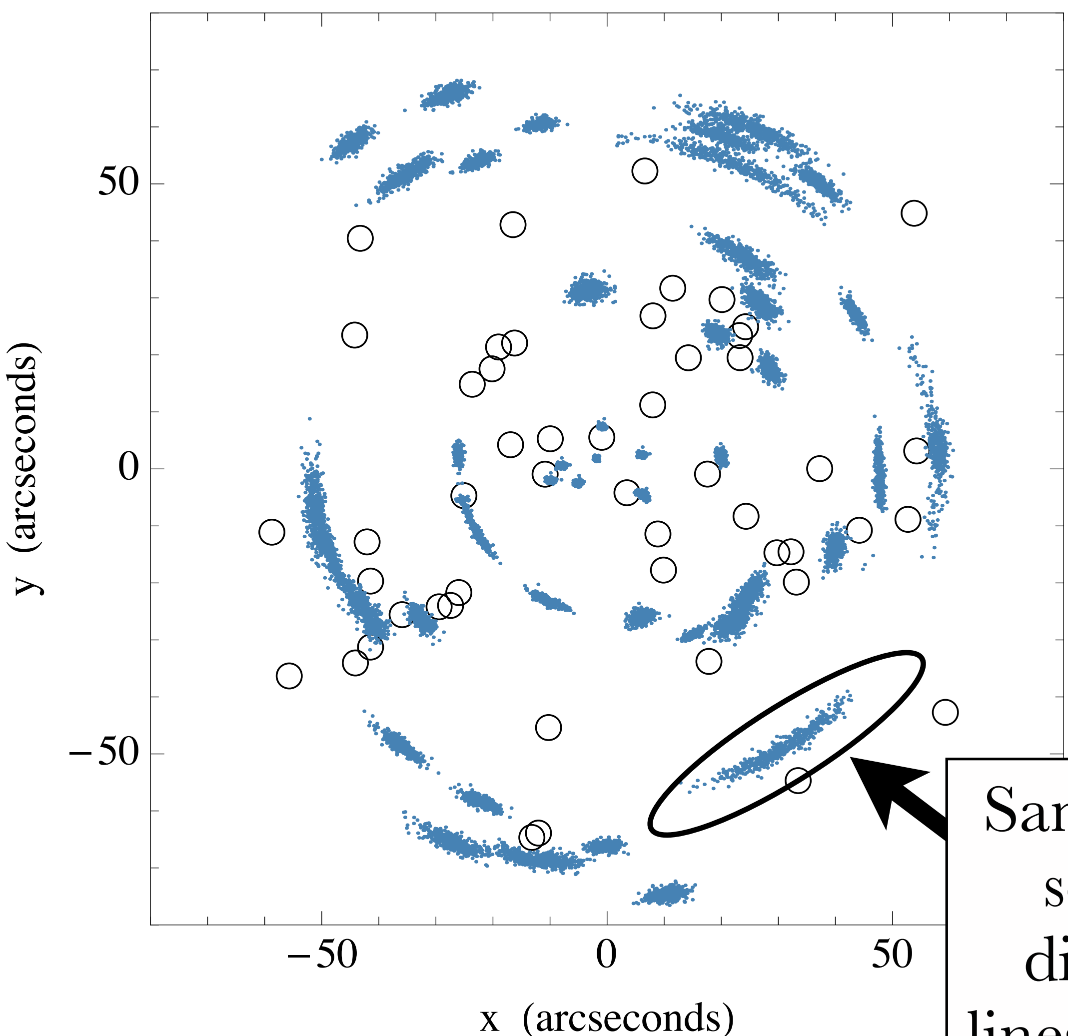
Note, these magnification effects are NOT simply additive.

Intervening Large-Scale Structure

- LSS's relative deflection of images: ~2 arcsec. (D'Aloisio & Natarajan 2011; Host 2011)

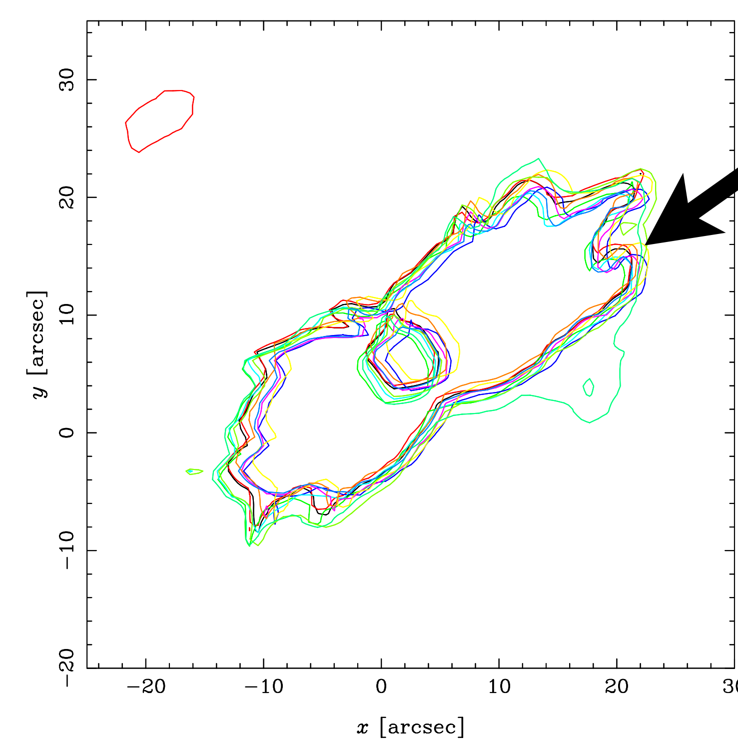
- Perturbs critical curves, boosts strong-lensing cross section by ~50% (e.g. Wambsganss et. al. 2005; Dalal et. al. 2005; Puchwein & Hilbert 2009)

- Cluster-lenses are on special lines of sight. (Bayliss, Johnson, Sharon et. al. 2014)



Same point source, different lines of sight

*From D'Aloisio & Natarajan 2011



Different lines of sight

*From Dalal et. al. 2005

see e.g. Wambsganss et al. 2005; Dalal et. al. 2005; Hilbert et. al. 2007; Puchwein & Hilbert 2009; Jullo et. al. 2010; D'Aloisio & Natarajan 2011; Host 2011

Intervening Large-Scale Structure

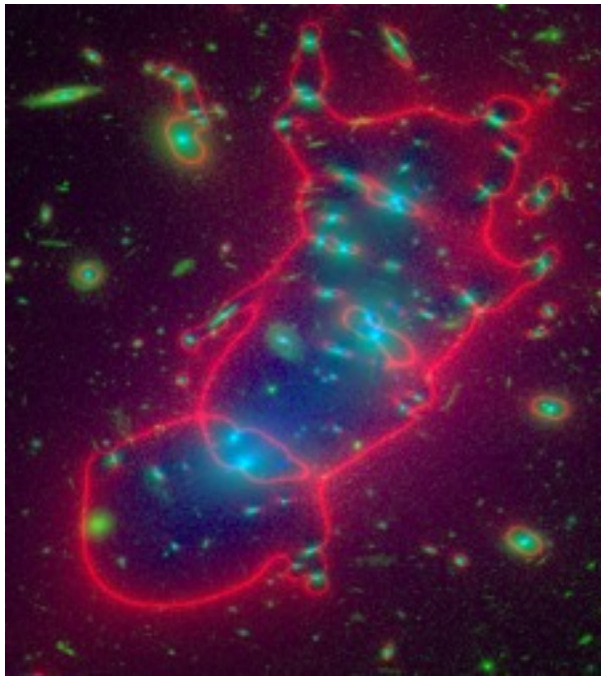
Question: How much can LSS contribute to the magnification maps of cluster-lenses?

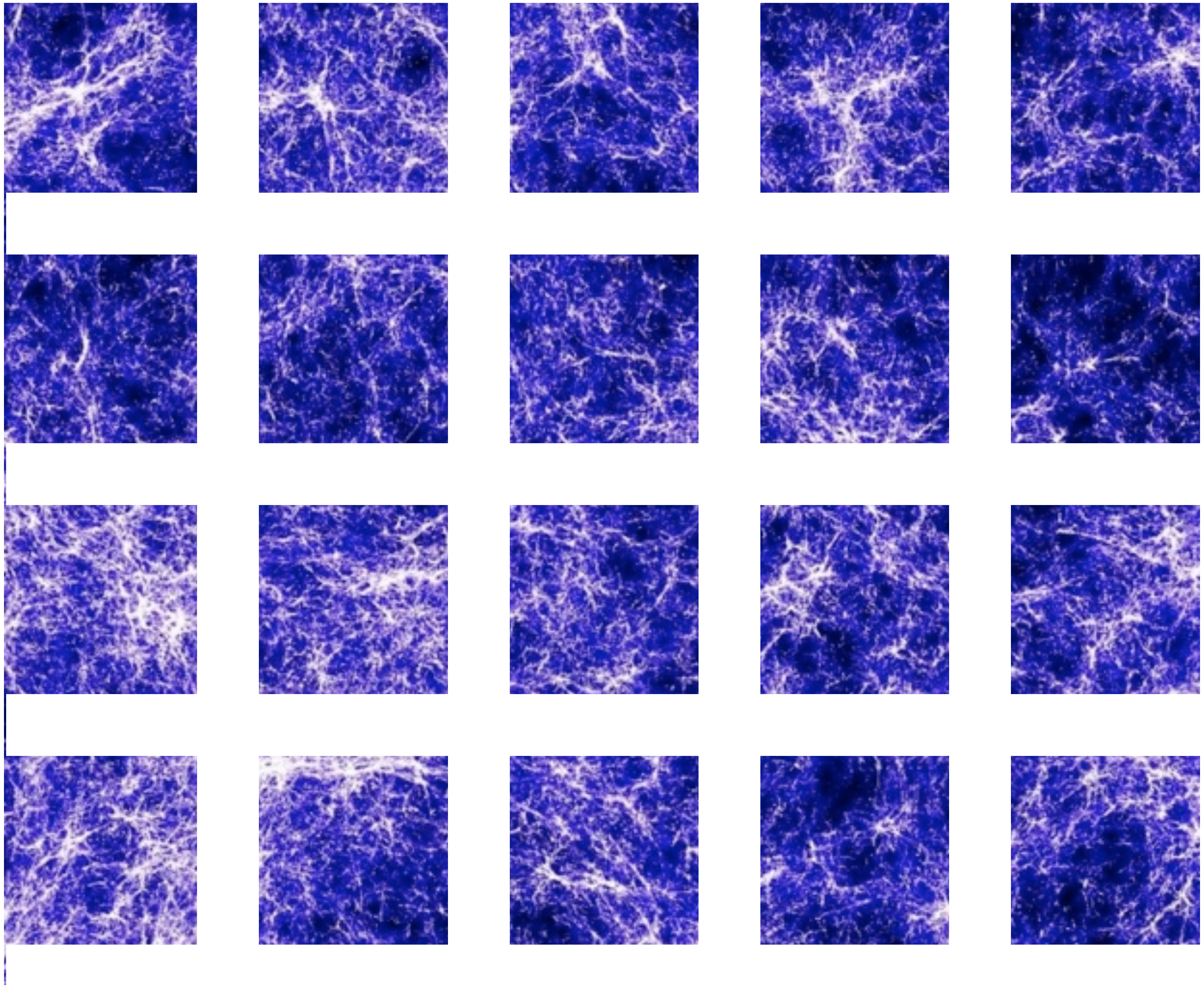
- Approach: “semi-analytical” based on nonlinear matter power spectrum.
- A useful precursor to simulations:
    - Shot noise in ray-tracing, especially for large μ. (Bradac et al. 2004; Amara et al. 2006; Li et al. 2006; Xu et al. 2009; Rau et. al. 2013; Angulo et al. 2014)
    - Finite mass-resolution of simulations, and power from $0.01 \lesssim k \lesssim 1000\ \mathrm{Mpc}^{-1}$ contributes! (see arXiv:1311.1614)

The Calculation: Concept

Ensemble of LSS realizations

Isolated Cluster-lens

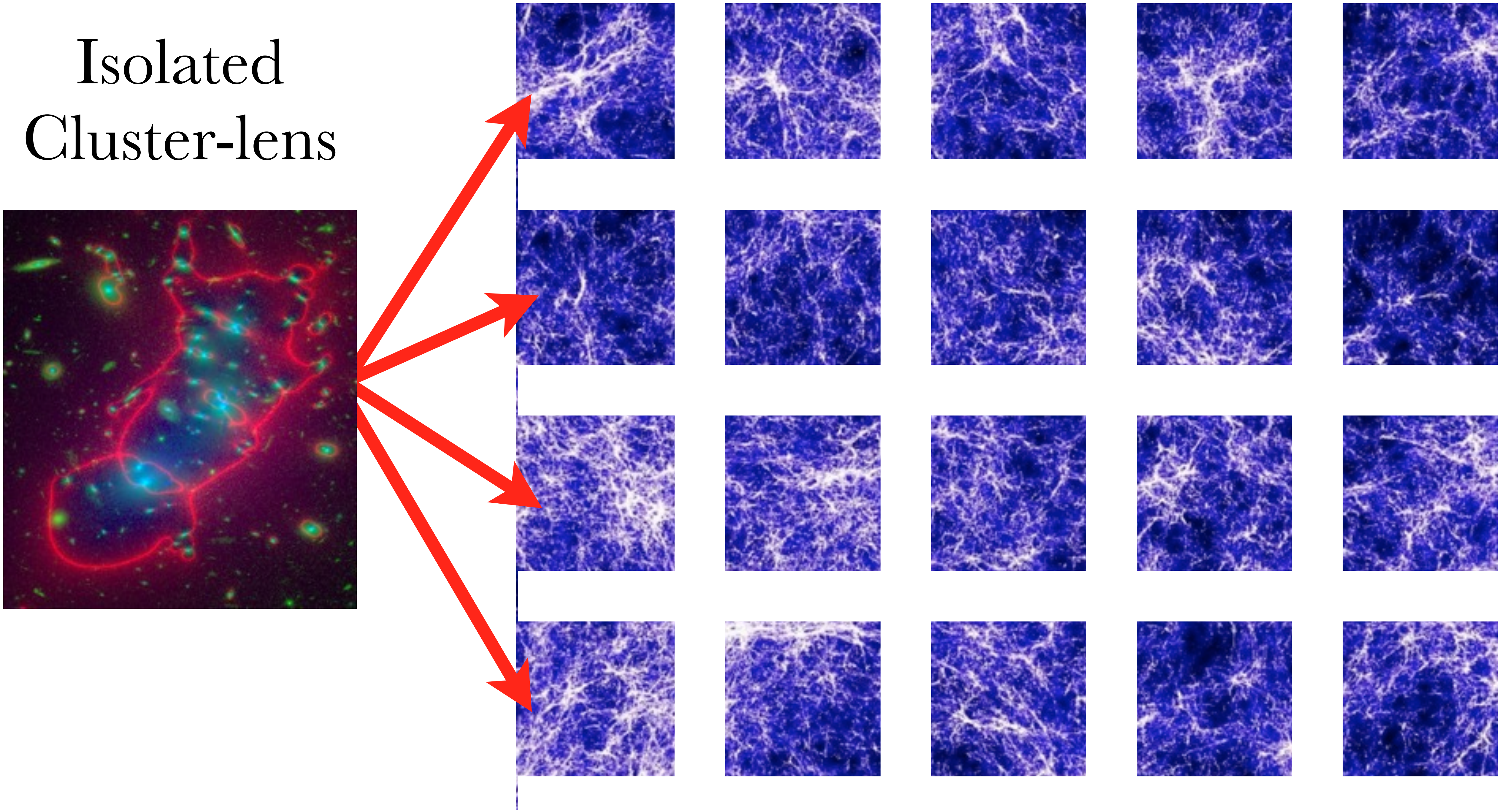




The Calculation: Concept

Stick the cluster in ensemble and measure fluctuations across magnification maps

Isolated Cluster-lens



The Calculation: in Practice

- Lens equation: $$\theta_{S,i} = \theta_{I,i} - \alpha_i(\boldsymbol{x}(\chi_L)) + \frac{2}{\chi_S}\int_0^{\chi_S} d\chi' \partial_i \Phi_{\rm LSS}(\boldsymbol{x},\chi')(\chi_S - \chi')$$

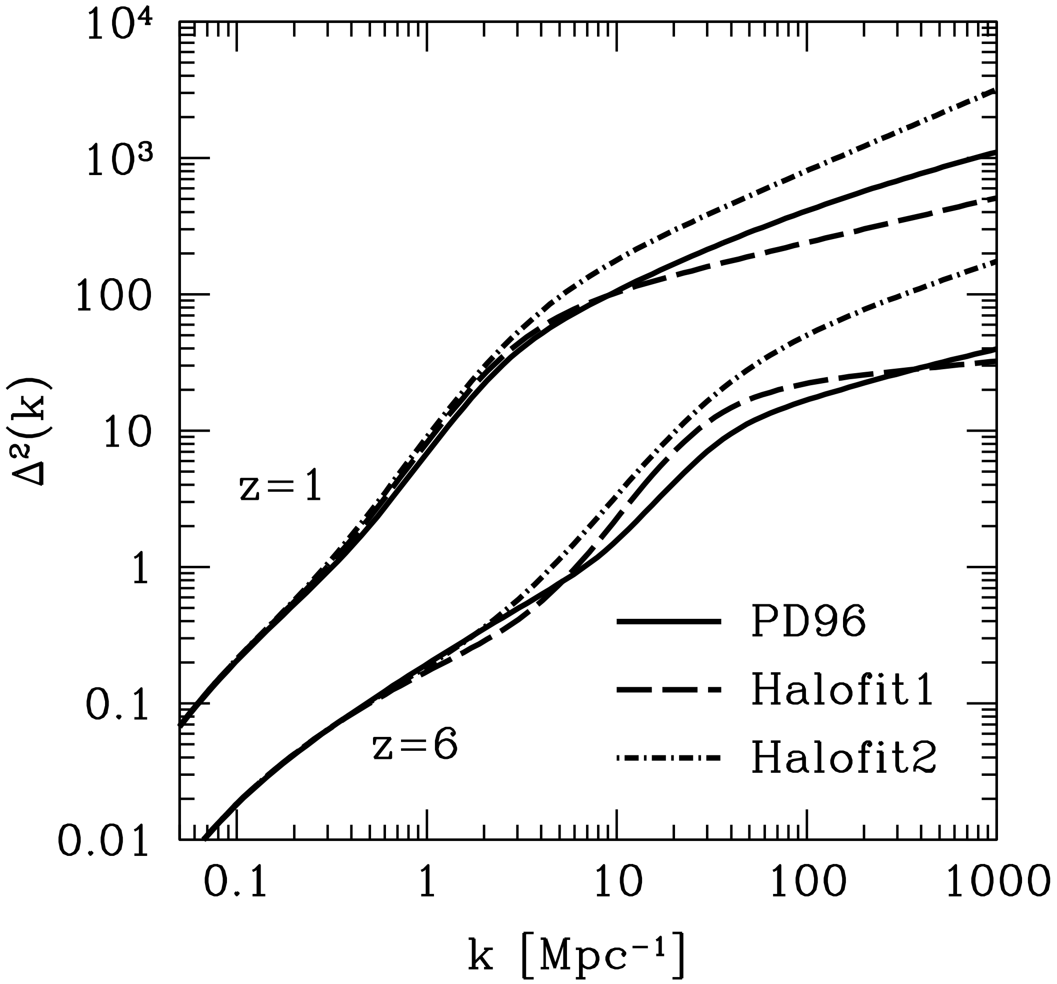
- Expand $\Phi_{\rm LSS}$ about x=0 (Barkana 1996)

- Calculate fractional standard deviation of $1/\mu$

$$\frac{\sigma_{1/\mu}}{|\langle\mu^{-1}\rangle|}$$

- LSS encapsulated in matter power spectrum, P(k).

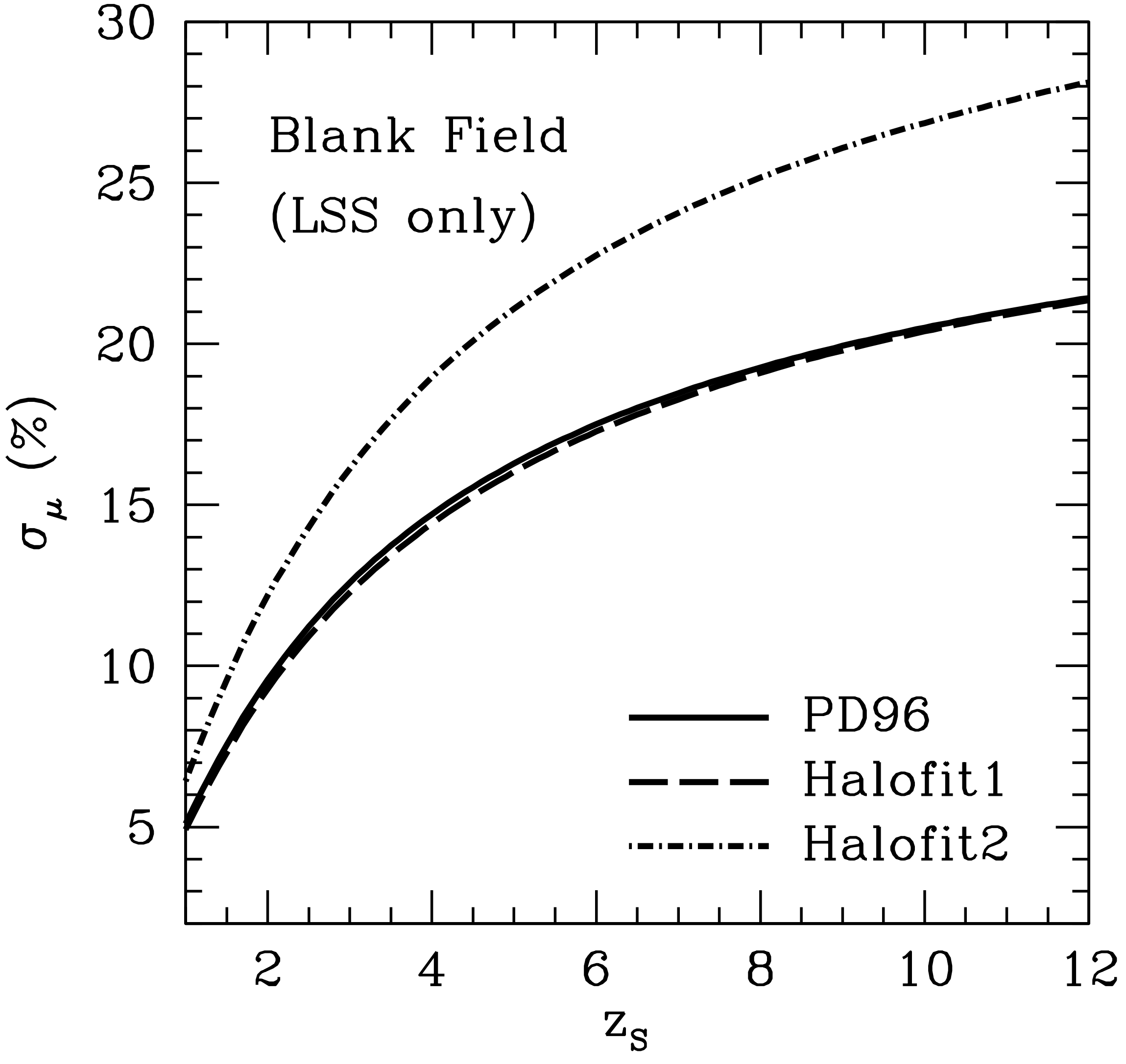
- Illustrative purposes: NFW lens.



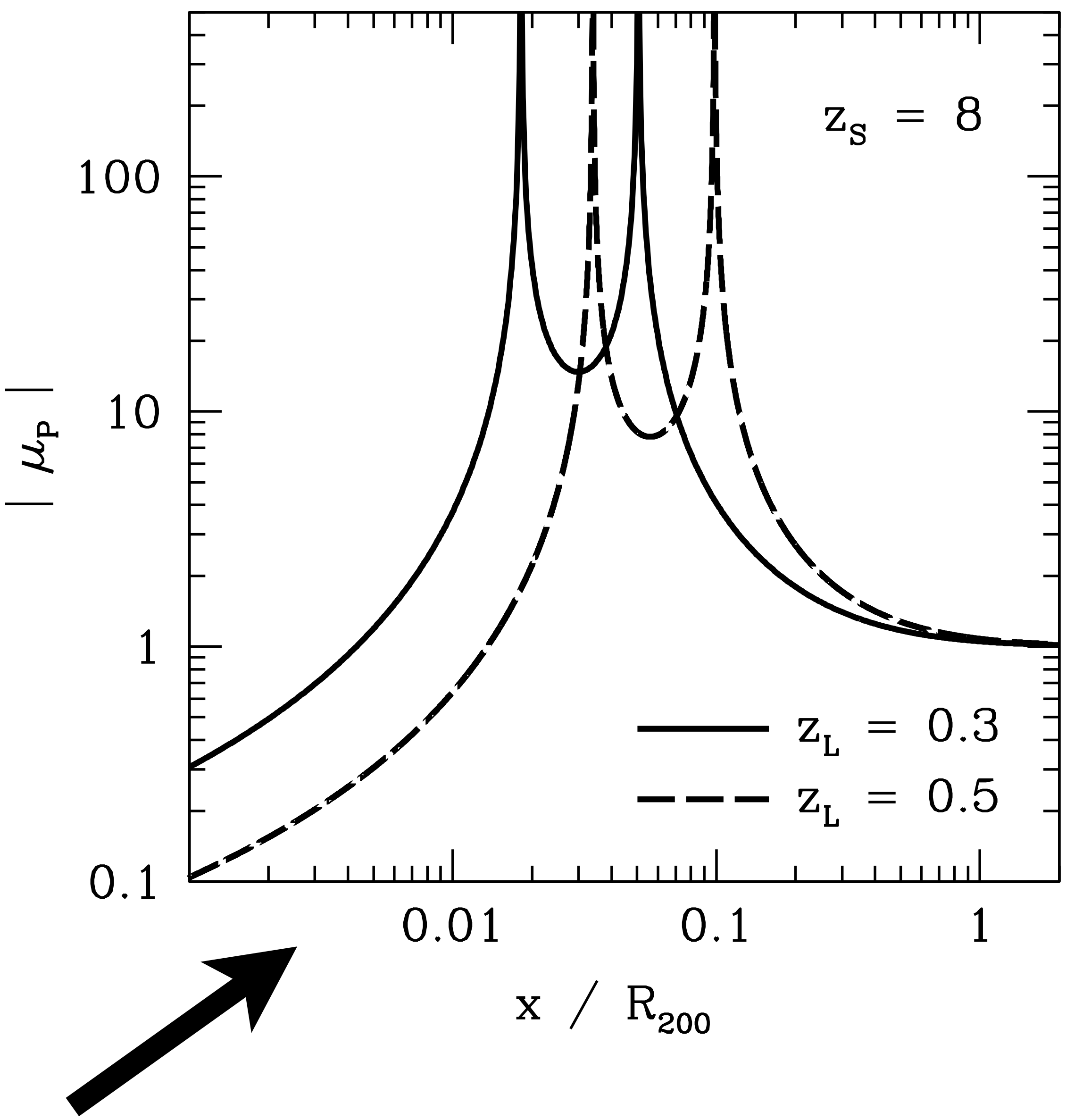
PD96 = Peacock & Dodds 1996
Halofit1= Smith et. al. 2003
Halofit2 = Takahashi et. al. 2012

LSS ("Blank Field") and Cluster Separately

LSS only



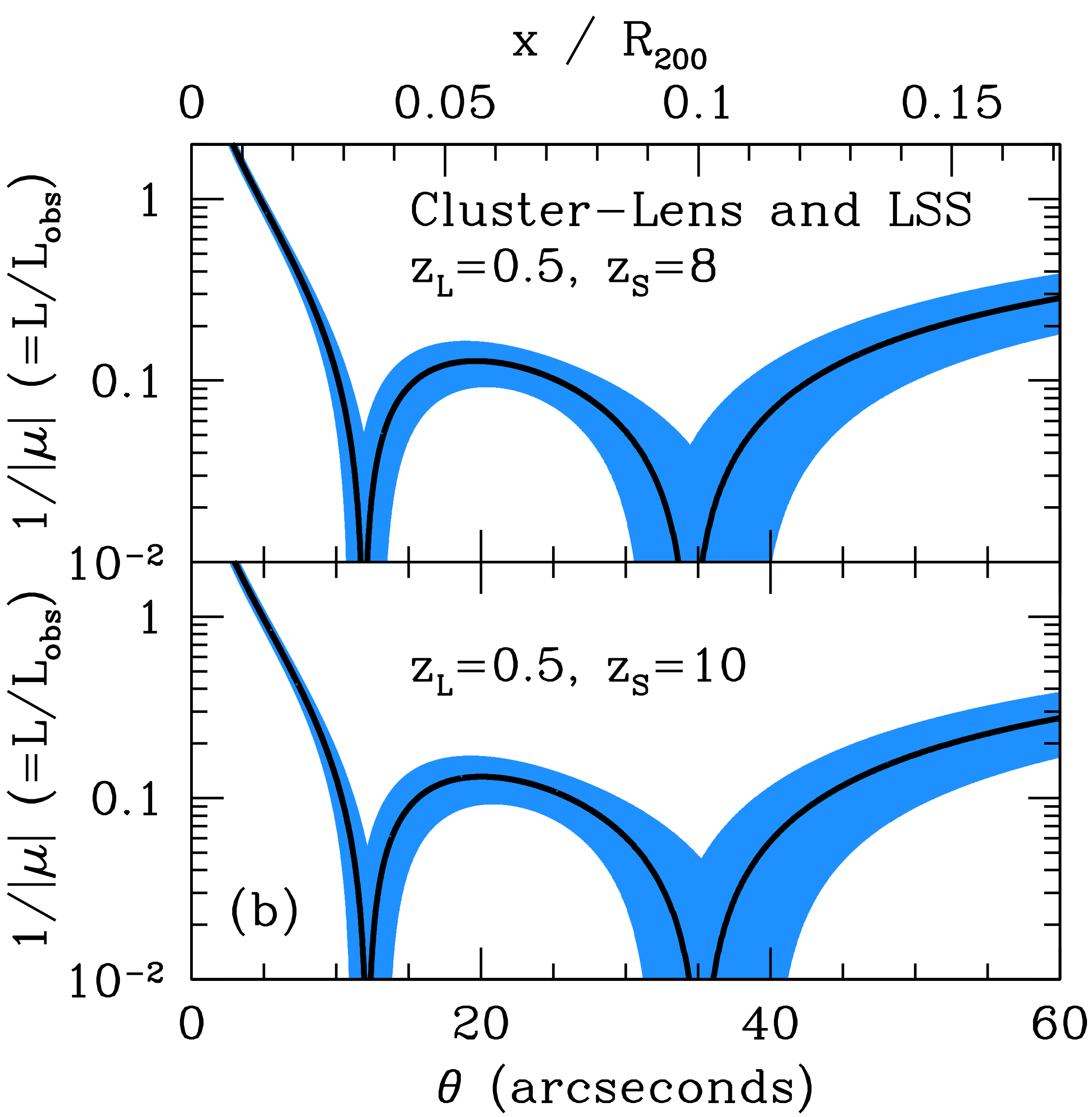
Cluster only

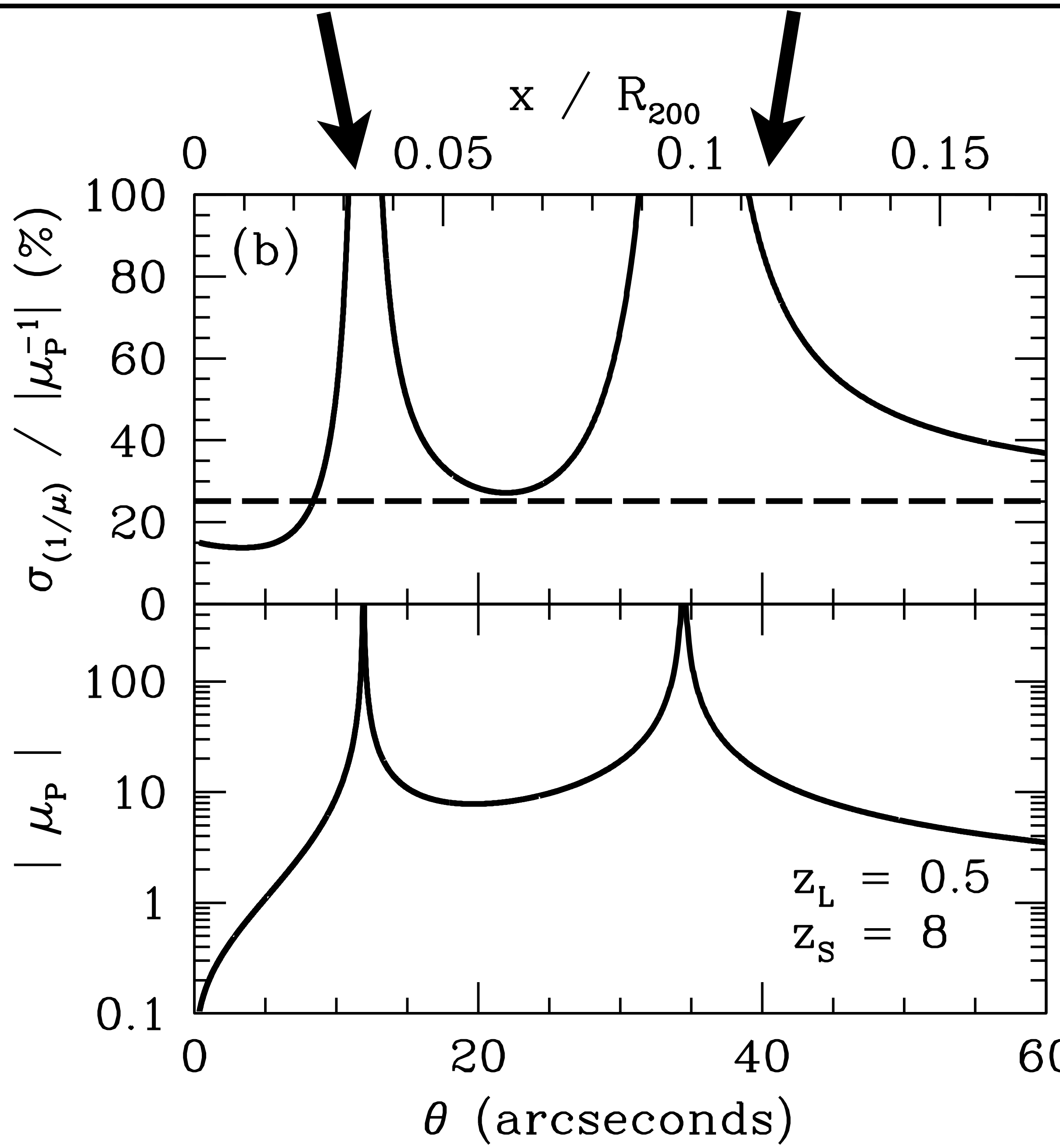


Simple NFW model (Bartelmann 1996) with $M_{200}=2\times10^{15}\ M_\odot$, $c_{200}=4$

LSS and Cluster Combined

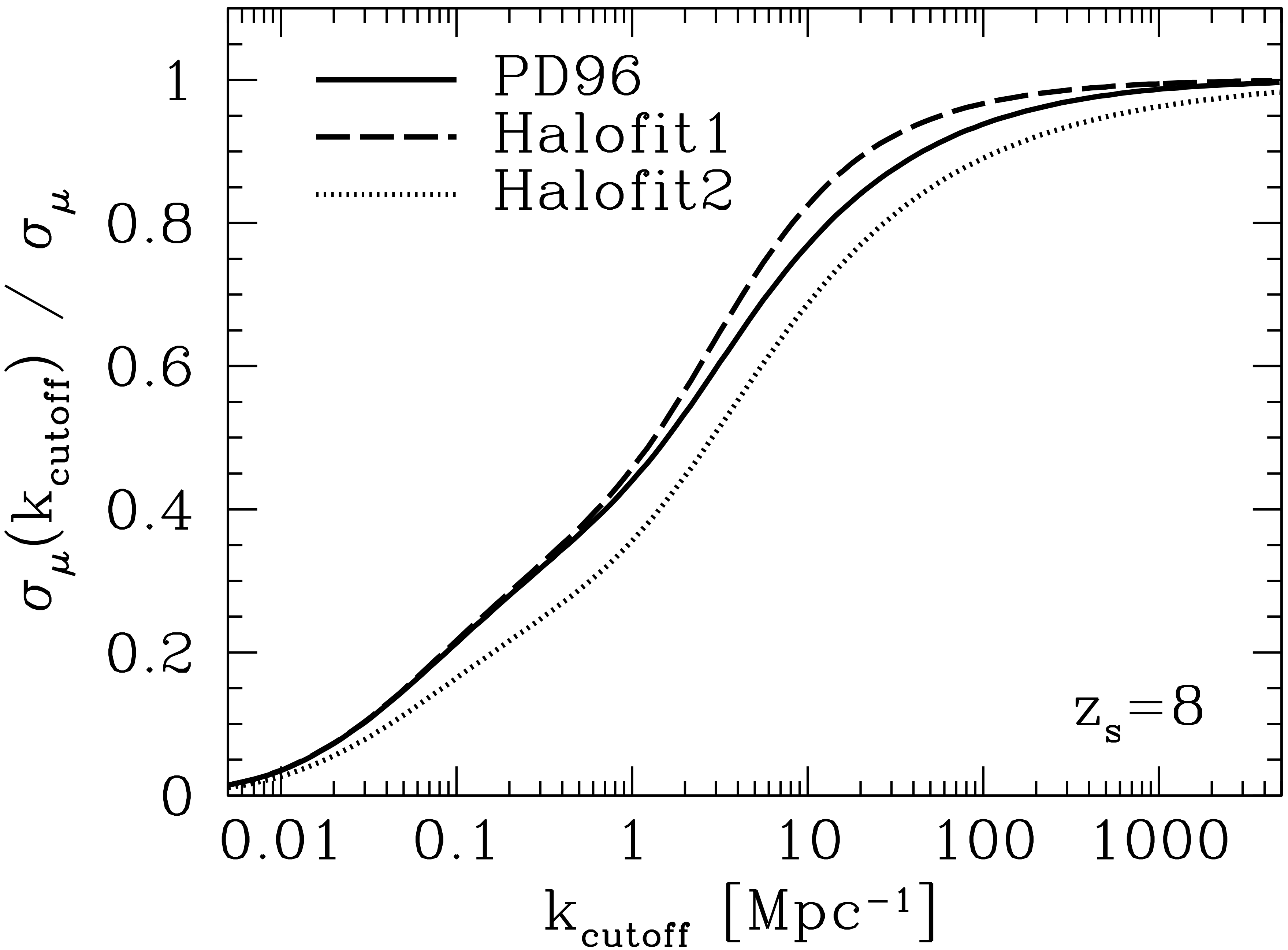
Because LSS perturbs critical curves





Results here from Halofit2 power spectrum

Contribution of “Small-Scale” Structure



Conclusion

- For cluster-lenses at $z_L \sim 0.5$, fluctuations in the μ of sources (from LSS) at redshifts $z_S > 6$ are ~10-20(20-30)% for typical $\mu \sim 5(10)$.

- LSS tends to have its largest impact on the most magnified images (greater than order unity fluctuations in μ near critical curves!).

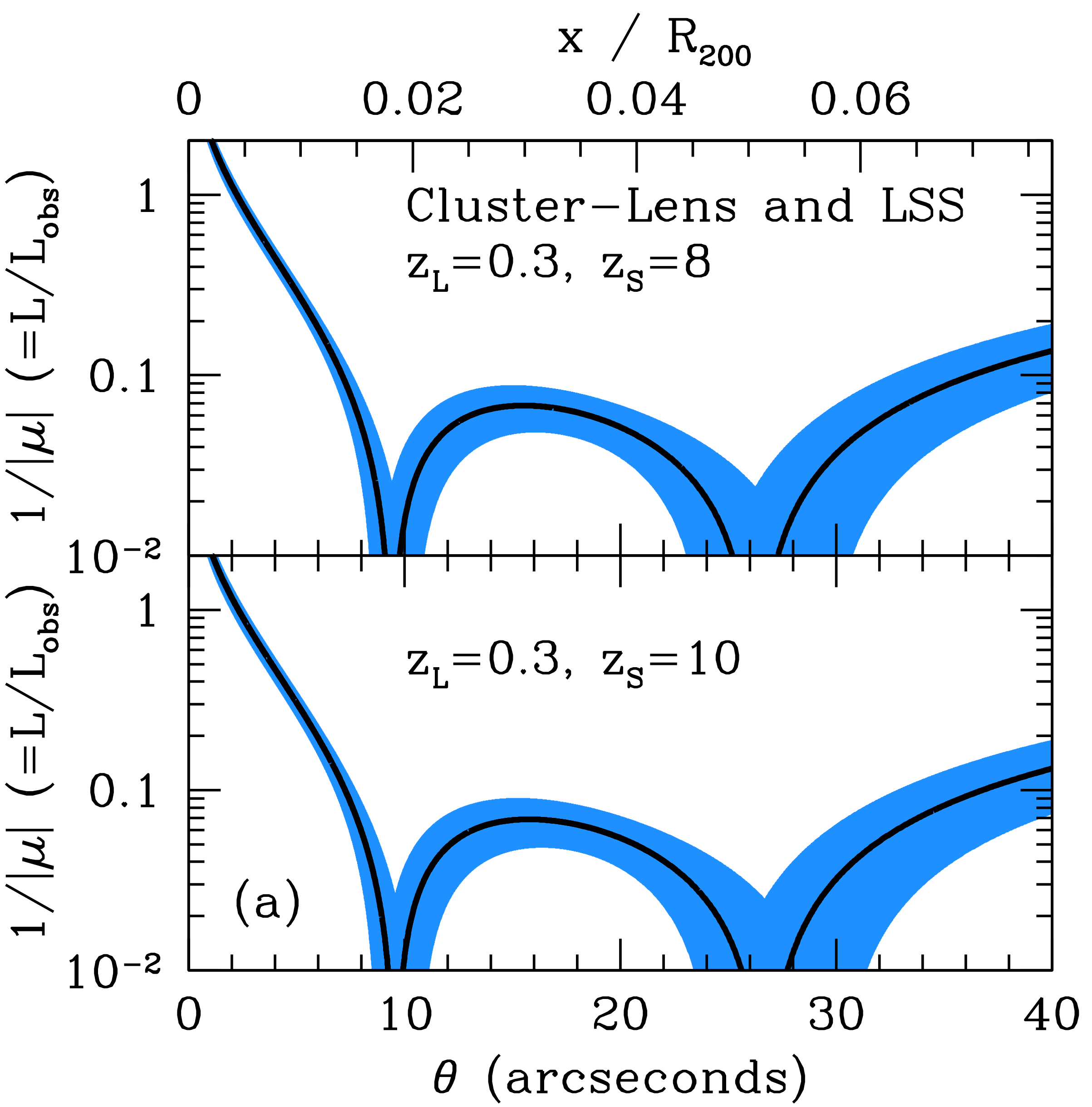
- These numbers do NOT represent μ-measurement errors.

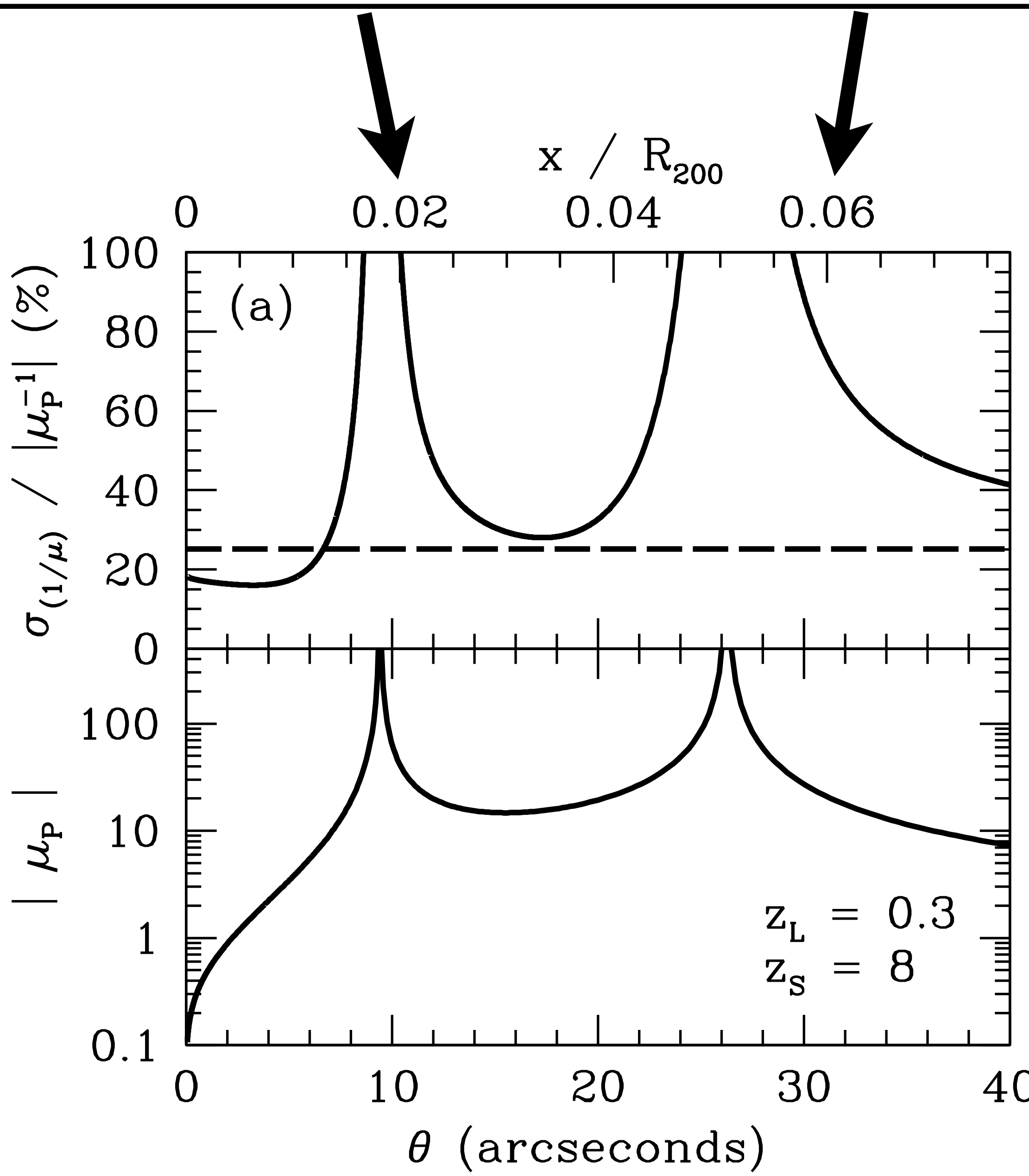
- These results do NOT preclude accurate μ-measurements, e.g. may be possible to model LSS by extending existing methods to case with multiple source redshifts.

- Motivates future numerical work towards quantifying effects of LSS in cluster-lens reconstruction (e.g. Frontier Fields Comparison Project).

LSS and Cluster Combined

Because LSS perturbs critical curves





Results here from Halofit2 power spectrum